SUPPLEMENT TO "NATURE."

LORD KELVIN ON OPTICAL AND MOLECULAR DYNAMICS.

Baltimore Lectures on Molecular Dynamics and the Wave Theory of Light. By Lord Kelvin, O.M., G.C.V.O., P.C., F.R.S. Pp. xxii+694. (Cambridge: University Press, 1904.) Price 15*s.* net.

IN the autumn of the year 1884 Lord Kelvin delivered at Johns Hopkins University a course of lectures "On Molecular Dynamics and the Wave Theory of Light," mainly *extempore,* which, having very fortunately been reported stenographically by Mr. A. S. Hathaway—one of his band of auditors, the famous "twenty-one coefficients"—were issued to the world unrevised in a papyrograph volume at the end of the same year, and have since been known as the "Baltimore Lectures." The report, being nearly *verbatim,* showed how comparatively slight were the immediate preparations that Lord Kelvin had made for some portions of his task, and thus had the great advantage of revealing the procedure and attitude of an investigator of transcendent genius in face of regions of his subject more or less new to him.

One result, in fact, of his enthusiasm for the new aspect of optical propagation revealed by the phenomena of anomalous dispersion, and of the wealth of mechanical illustration which, taking his audience into collaboration, he provided for this hitherto rather abstract subject, was to start a period of enlivened interest, illustrated by memoirs by Lindemann and others, abroad and in this country; this has now reaped a reward in fruitful comparison of the theory with experimental data obtained over the enormous range of six or seven octaves by Langley, Rubens, and other pioneers. Irrespective of this phenomenon of anomalous dispersion in the spectrum near a region of absorption of the light, Lord Kelvin's own estimates of molecular dimensions had already ruled out the earlier attempts of Cauchy and his followers to base dispersion on mere loading of the æther by massive molecules. On such a theory of inert molecular masses the proportional dispersion per octave could depend only on the ratio of the intermolecular distance to the wave-length, no other magnitudes coming into consideration, and it must depend on the square of this ratio; thus the actual 1 per cent. dispersion for glass would be explicable by about 10 molecules per wave-length, while with the real number, about 10^4, the circumstances would be practically the same as for a uniformly distributed load, which would give no dispersion at all. The modern theory of dispersion thus must rest on an investigation of the interaction between the forced internal vibration of the molecules, conditioned by their own proper periods, and the periodic impressed vibration of the wave-motion which produces it. So long as the internal dynamics of the molecule remain unexplored, only general principles can be applied, and it matters little to the argument whether it is conducted in terms of a mechanical conception of radiation or in terms of the electric theory; in either case only the general frame into which the facts are to be fitted can be supplied by theory. On a mechanical view, mere loading may produce refraction but not dispersion; so on the electric view, even if there were no free periods in the ordinary sense, there would remain an index of refraction equal to the square root of the dielectric coefficient.

In the preface to the present volume Lord Kelvin states that he chose for his lectures the subject of the wave-theory of light with the object of accentuating its points of failure, thereby intending to stimulate the activities of his audience towards extending further "the floods of new knowledge splendidly enriching the whole domain of physical science" that had flowed from the theory.

> "We all felt that difficulties were to be faced and not to be evaded; were to be taken to heart *with the hope of solving them if possible*; but at all events with the certain assurance that there is an explanation of every difficulty, though we may never succeed in finding it. It is in some measure satisfactory to me, and I hope it will be satisfactory to all of my Baltimore coefficients still alive in our world of science, when this volume reaches their hands; to find in it dynamical explanations of every one of the difficulties with which we were concerned from the first to the last of our twenty lectures of 1884."

The sentences quoted contain the key to much (though far from all) of Lord Kelvin's mathematical investigation of the last twenty years. The result is this magnificent volume of more than 700 pages, which in its variety of contents and width of grasp forcibly recalls the original "Thomson and Tait" of forty years ago, except, indeed, that the form of a treatise being now dispensed with, the author is at liberty to go directly for the various subjects of interest that hold his attention without any necessity for preliminary didactic expositions.

The earlier lectures are reproduced here with additions within brackets, but the author soon found that it was easier to re-write the greater part of the material. His expression of distrust of "the so-called electromagnetic theory of light" (p. 45) stands as in the original. Along with it is the interesting statement that he had worked out for himself, as early as the year 1854, the result that an electric impulse is propagated along a cable with a velocity of the order of that of light, and that it only required a knowledge of the ratio of the electric units to lead to the result that for an air dielectric it would agree with the velocity of light in air. An investigation of such linear propagation, on the lines now familiar, and thoroughly developed by Heaviside, is inserted as the last appendix (L). The first published determination of this velocity is contained, as is well known, in Kirchhoff's memoir of 1857; there the result is deduced on the basis of Weber's theory of moving electrons, which act on each other instantaneously at a distance, the law of attraction involving their velocities as well as their distance apart. Neither there nor in the ordinary modern investigation for cables is there any reference to transmission of electric effects across space with finite speed; that makes no difference for the case of enclosed cylindrical dielectrics of diameter small compared with the wave-length, for with them it is only the adjacent parts of the electric distribution and current on the conducting boundaries that are sensibly effective as regards the internal state of each element, and their mutual influences are adjusted in times which are in any case inappreciable in an estimate of the times required for transmitting effects along the cylinder. For wider cylinders or shorter waves, the Weberian formula of Kirchhoff gives a result differing from the velocity of radiation, of which Maxwell was of course well aware, while Lord Kelvin's approximate treatment is no longer applicable. We now know that, to transform the Weber-Kirchhoff formulæ into those of the modern electron theory, it is only necessary, in the integral expressions for the vector potential of the current and the scalar potential of the charges, to consider each element as propagated through space with the velocity of radiation instead of being transmitted instantaneously.

One of the great historical difficulties in optical theory, above referred to, was that of embracing the phenomena of propagation in crystals and of reflection from transparent bodies within the dynamics of ordinary elastic solid media. This problem was resolutely attacked by Green nearly sixty years ago with a brilliant but unsuccessful result, and no success in adapting his analysis was achieved by anyone else until some three years after the Baltimore lectures were delivered. Then Lord Kelvin produced his theory of an elastic medium with finite rigidity but perfectly labile as regards compression, and characteristically illustrated it by material structures, such as a mass of foam *in vacuo*, which resist distortion but are insensitive to shrinkage of volume. If luminiferous media were elastically like this, the necessity of continuity of displacement normal to a reflecting interface would no longer press upon the theory, for the two media would stretch locally in the direction of the normal without reaction on the other stresses, just as much as might be required. And it was promptly pointed out by Glazebrook that the arrangement which thus allowed Fresnel's laws for reflection was also competent to explain propagation in crystals by the simple expedient of making the inertia æolotropic, while the lability as regards compression is again all that is wanted to obtain the ascertained laws of MacCullagh's theory (Lord Kelvin's rotational æther) or the electric theory for crystalline reflection. In fact, one advantage accruing with the electric theory is that it dissects the accepted and unique formal analysis of propagation of light into a series of linear relations between various vectors, each of which has a distinctive name and quality; and according as we take one or other of these vectors to represent a displacement of an elastic medium, we have the various mechanical theories of Fresnel, MacCullagh, and Sarrau and Boussinesq, differing in the types of interfacial continuity that they require, but algebraically the same; the exact duality between the systems of Fresnel and Sarrau is in this way open to direct inspection. Such, then, was Lord Kelvin's solution of 1887, in which all media were taken to be labile as regards compression, the type which Green had rejected under the idea that it was intrinsically unstable; this classical objection Lord Kelvin at once removed by the illuminating remark that the medium only required to be held fixed at an outer boundary to prevent any internal collapse. There was something unnatural about this, as its author admitted, and it now appears that an æther so constituted would still absorb much condensational energy from vibrators; but here in 1904 comes the further crucial remark that only one of the two media need be thus labile in order to confer the requisite freedom for reflection without interference from compressional waves; the æther itself may remain incompressible, as Green took it to be, but the interaction of æther and molecules in every material body is to be such as always to make it labile or inelastic for compressional disturbance. It need not, however, be absolutely labile if Fresnel's laws are to be satisfied only within experimental limits. And here the remarkable peculiarity of highly refractive substances like diamond, the "adamantine property" discovered by Airy, which replaces an abrupt change of phase in passing the polarising angle by a gradual though rapid one, comes into consideration; if only the velocity of propagation of the condensational wave in material media is a small complex quantity, the complexity will introduce just the gradual change of phase that is required in order to include that property. Moreover, if this velocity is a pure imaginary, there will be no loss of energy involved; this happens for a granular or discrete medium whenever there are periods of free internal vibrations among its constituent granules that are longer than the period of the waves under consideration. If we cannot include the adamantine property as introduced in this way through total reflection for compressional waves, no resource is known except that of gradual transition at the surface; this Lord Rayleigh has shown to be the main cause for water, as careful cleansing of the surface almost entirely removes the phenomenon.

In this chain of simple, yet brilliant and attractive, ideas, Lord Kelvin has gradually forged a reconciliation between fact and theory that would probably have been received with universal acclaim thirty years ago. Nowadays, as regards most people, the need has ceased to be so strongly felt; for better for worse most of us are now wedded to the electric theory of light, the creation of Lord Kelvin's most famous disciple, which forms a consistent scheme of the relations of electricity and radiation, perfectly definite and unambiguous with the large simplicity of nature itself, that has led into no essential contradiction with fact, though it has many times predicted phenomena of the most essential and fundamental kinds.

Not that there is any difference of opinion as to the value of the electric theory. Lord Kelvin would doubtless agree that, as a new mode of grouping of the relations, it has placed them in a most fruitful light, and shown the directions of natural development. He would perhaps say that it is a successful description rather than an explanation, and he would probably desire to modify the terms of the description in order to bring it closer to the train of dynamical ideas in which he would search for the explanation. And here we are at the parting of the ways. Is it incumbent on us to treat the æther as strictly akin to the material bodies around us? or may we assign to it a constitution of its own, to be tested by its success in comprehending the complex of known relations of physical systems? This is not the occasion to follow up that question. It would appear that Lord Kelvin cannot grant that such a constitution has been determined until it has made clear in full detail the mode of connection of the atom with the æther, so that a precise mechanical model of it could be imagined; whereas, on the other side, it may be held to be the merit of the scheme that it evades such a hopeless task, and defines physics as relating to the surrounding field of æthereal activity of the molecules rather than to the molecules themselves, which must remain in many respects inscrutable—a consummation that would hardly have been attempted had not the illuminating conception of Lord Kelvin's vortex-atoms shown the way.

The plan along which Lord Kelvin now finds it most hopeful to pursue ultimate physical synthesis admits the existence of "electrions," freely mobile through æther simply because two media can be superposed independently in the same space, which exert direct *force at a distance* upon the æther as also does the matter itself, that the forces are so enormous as sensibly to compress or expand the æther around these nuclei, and that the source of electric, chemical and elastic action is thus to be found. This conception is developed over many pages with the power and conciseness that are familiar to his readers; it remains a question for the future whether it will prove to be a fruitful theory; it certainly forcibly illustrates many deep molecular phenomena, and demands, and will doubtless receive, very careful study.

The point of view is illustrated in p. 300, in treating of the spheres of activity of the various kinds of molecules, where Lord Kelvin states that this "is a most interesting subject for molecular speculation, though it or any other truth in nature is to be explained by a proper law of force according to the Boscovichian doctrine which we all now accept (many of us without knowing what we do) as the fundamental hypothesis of physics and chemistry." When one reflects that to Lord Kelvin, more than to anyone else except Faraday, has been due the stimulus to replace artificial mathematical attractions by activity propagated according to simple relations, this sentence may perhaps be taken as expressing his belief that in probing into the details of the dynamics of the unexplored molecules we are still practically confined to the partial but fruitful conception of mutual forces.

Thus in the appendix entitled "Aepinus Atomized," a definite foundation is postulated by taking the electrion to be a very minute negative ionic charge, and an atom to involve a positive ionic charge rigidly distributed through a much larger sphere, but in normal condition neutralised by one or more electrions inside it, which may be occasionally shot out as kathode rays; and electrions and atoms can be wholly or partially superposed in the same space without mutual deformation. On this basis the statical configurations of electrions in the spheres, that can represent neutral atoms, are discussed and are applied to the dielectric quality of matter and its æolotropy in crystals, to the intricate and elegant details of the pyroelectric and piezoelectric quality in the latter, and in more general terms to the nature of conduction and its striking relation to temperature, so different in pure metals and in non-metals and alloys. In further appendices the same conception is applied to crystalline dynamics, where auxiliary Boscovichian laws of pure attraction are also introduced, because Lord Kelvin thinks a purely electric basis is too narrow, even when not restricted to spherical nuclei as here. The whole is developed on all sides with marvellous directness and facility in tracing out crystalline groupings in space, which, however, make it difficult reading, though relieved by frequent flashes when a vivid analogue of some ascertained experimental relation appears. It is a conception such as this that Lord Kelvin has in mind in his postulate, above referred to, that material bodies are labile to optical compressional waves. The free molecular vibrations that must correspond to a bright line-spectrum do not come in for consideration; nor does the now burning question of actual dissociation in typical chemical atoms.

The task of making a review of a book like the present one can at best be very imperfectly executed. The book is largely a new creation. It surveys a vast range, all the cognate subjects on which the author feels that he has something new to communicate—laws of diffusion of gases, transparency of the sky, detailed dynamics of optical chirality, motion of molecules through æther, front of a wave-train in a dispersive medium, the finiteness of the universe, atomic theory of electricity, regelation and plasticity of ice, waves and ripples on water and their dispersion, crystalline structure and iridescence, partition of energy in molecular systems, crystalline dynamics on Boscovich's principles, electric and magnetic screens. Instead of putting the question, Is this subject clearly and strikingly expounded? one has rather to ask, Is this new departure or revolutionary idea justified by its results? Any off-hand decision is, of course, impossible. When one is in difficulty over inscrutable or irreconcilable phenomena, it will be a book to turn over to see what the premier authority has to say on the subject in hand; for what he says is not lightly thrown from his pen, it is the work of twenty years, and withal it forms a consistent whole. In the remarks here made about only a few of the many themes of which it treats, it is the obviously revolutionary element that has attracted attention. There is, however, one very serious criticism as to which there can be no question. This book of seven hundred pages—dealing in concise manner with nearly all the most intricate topics of dynamical and molecular theory, with the cross references and recurrences to previous passages that are involved in twenty years of preparation—is without an index, and the detailed table of contents does not meet the want. The thanks of the scientific world will surely go to the veteran author, now by a happy choice Chancellor of the university which he has so long adorned, for this splendid gift, which stimulates and educates even where it fails to convince, and bears on every page evidence of profound and unwearying thought. J. L.